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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Surveyor Penetration in a Model Lunar Soil

TM-67-1014-5

DATE- September 6, 1967

FILING CASE NO(S)- 340

AUTHOR(S)- E. N. Shipley

FILING SUBJECT(S)- (ASSIGNED BY AUTHOR(S)- LM
Landing Dynamics
Landing Simulations
Lunar Surface Properties
Soil Mechanics
Surveyor

ABSTRACT

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DATE: September 6, 1967

FROM: E. N. Shipley

TM-67-1014-5

TECHNICAL MEMORANDUM

1.0 INTRODUCTION

This memorandum gives a report of the extension of earlier work done on simulating Surveyor landings on model soils.(1) The previous work was aimed at interpreting the footpad penetration data obtained from the Surveyor I spacecraft and providing an estimate of LM performance in soils which were compatible with the Surveyor data.

The purpose of this report is to bring the Surveyor simulations up to date by inclusion of the new shock absorber which was flown on Surveyor III and which will be used on all subsequent flights.

The simulation technique and the soil model which are used here are essentially the same as those used in the previous report, and the reader is referred there for a complete discussion. The principal limitations of the previous study were that only a single model was considered and that the spacecraft motions were restricted to be in the vertical direction. These limitations remain in the current extension of the work.

The simulations were performed on Bellcomm's IBM 7040/7044 digital computer. At a given time t, the spacecraft and footpad accelerations were calculated, and the value was used to propagate the position and velocity forward for a time interval Δt, which was taken to be .0002 seconds. The footpad and the landing gear are considered to be massless, and any horizontal forces at the footpad are, in general, neglected.

The soil model used in this and in the earlier study represents an incompressible soil. The properties of the soil are described by three parameters: the angle of internal friction, the density and the cohesion of the soil. Dynamic forces in the soil are taken into account. A complete description of the soil model has been given by Chandeysson.[2]

A subsequent memorandum will report on further studies which are concerned with interpretation of the shock absorber strain gage data which are obtained during a Surveyor landing. Provision has been included in the simulation program to model the filter which limits the high frequency response of the strain gage.

2.0 THE NEW SURVEYOR SHOCK ABSORBER

2.1 Description

The new Surveyor shock absorber was used on Surveyor III and IV, and it will be used on all subsequent spacecraft. It differs from the previous shock absorber in both spring constant and damping constant. In addition, the model of the shock absorber used in these studies now contains a term representing the frictional force within the shock absorber. No such term was included in the model of the shock absorber for Surveyor I (the "old" shock absorber), although such forces were in fact present.

The shock absorber force, F_a, is determined by the equation

$$F_a = K(s) + g(s) \left(\frac{ds}{dt}\right)^2 + ff \qquad (1)$$

where s is the stroke of the shock absorber, K(s) gives the preload and the spring force, g(s) is the damping constant, and ff represents the friction force.[3]

The spring force for the new shock absorber is shown in Figure 1 in comparison with the function used for Surveyor I. For Surveyor I, the spring was represented by a preload force plus a constant times the stroke. For the new shock absorber, the spring force is a more complicated function of the stroke. The important characteristic as far as the landing simulation results are concerned is the increased force level at all values of the stroke.

The damping constant function, g(s), for the new shock absorber and that for Surveyor I, is shown in Figure 2. Note that on the rebound stroke, the damping constant for the new shock absorber is significantly smaller than for Surveyor I.

The magnitude of the friction force is obtained from the relation

$$|ff| = 40 \text{ pounds} + .03\ K(s) \qquad (2)$$

No distinction is made between static and sliding friction. The direction of the force is opposite to the direction of stroking, so that it increases the shock absorber force during compression and decreases it during expansion. The force changes <u>discontinuously</u> where the stroke rate passes through zero.

There was no such discontinuity in the shock absorber model which was used for Surveyor I. Although the damping constant changes discontinuously between expansion and contraction, the stroke rate at this time is zero and no discontinuity in the shock absorber force is produced.

2.2 Characteristics of the Landing Simulation

The change in the shock absorber causes two distinctive alterations in the behavior of the landing simulation of Surveyor. These phenomena are discussed in this section. In all other characteristics, the behavior of the simulations is the same as for Surveyor I, except, of course, for the detailed results.

The sequence of events in the normal simulation is impact of the footpads, deceleration of the spacecraft simultaneously with compression of the shock absorbers and perhaps penetration of the footpads into the surface, expansion of the shock absorbers, and finally lift-off of the footpads from from the lunar surface.

For the old shock absorber, it was observed that the shock absorber fully re-extended before the footpads left the surface. For the Surveyor III shock absorbers the simulations indicate that in most cases lift-off will occur before the shock absorbers return to the fully extended position.

The other phenomenon results directly from the discontinuity in the shock absorber force when the direction of stroking changes. When the footpads and the spacecraft are moving downward with essentially the same velocity, a quasi-equilibrium situation is established in which the shock absorber oscillates between positive and negative stroke rate. The discontinuous change in the shock absorber force is sufficient to alter the trend of the motion and to cause the oscillation. In effect, the oscillation smooths out the discontinuity in the force by averaging, in time, between the positive and negative stroke rates.

Such behavior is likely to be peculiar to the simulation process. Various factors not considered in the simulations, such as flexibility of the landing gear and friction between the footpad and the soil, would function to smooth the transition between positive and negative stroke. The oscillation should not be regarded as a defect in the simulation but rather as a special behavior which arises from the specific choice of shock absorber model.

2.3 Penetration Data

The conditions under which the penetration simulations were run are the same as the conditions used in the earlier study except for the characteristics of the shock absorber. A detailed listing of the parameters is given in Table I. All of the simulations were run at a vertical touchdown velocity of 11.7 fps.

The results of the footpad penetration simulations are plotted in Figures 3 through 7. In each figure the footpad penetration is plotted as a function of cohesion for a constant angle of internal friction Φ, and a constant soil density, ρ. An additional scale which shows the bearing strength at the surface for a Surveyor footpad has been added. The results of the earlier simulation for Surveyor I are also shown for comparison.

The range of soil parameters which is shown in Figures 3 to 7 is more restricted than in the previous report. Only one curve is plotted for a density of 1 slug per cubic foot (Figure 5); the remainder of the curves have a density of 3 slugs per cubic foot.

The figures were plotted as a function of cohesion rather than bearing strength in conformity with the earlier work. Cohesion is a fundamental parameter of the soil model, while the bearing strength depends on the radius of the footpad.

The penetration data has been plotted as a function of the bearing capacity for Surveyor in Figure 8. The shaded areas show the range of penetrations which occur as the angle of internal friction is varied from 0° to 40°, for a given bearing strength. For both the old and new shock absorbers, the upper border corresponds to $\phi = 0°$ and the lower to $\phi = 40°$.

Figure 8 is intended to show the sensitivity of penetration to variation of the parameters of the soil model. For a given surface bearing strength, there is considerable variation as a function of the angle of internal friction. This arises primarily because the rate of increase of bearing strength with depth is much higher for $\phi = 40°$ than for $\phi = 0°$. The rate of increase of bearing strength is shown in Table II.

For the new shock absorber the maximum footpad pressure that is exerted when the spacecraft lands on a hard surface is 9.58 psi. Thus for any soil in which the surface static bearing capacity exceeds 9.58 psi, no penetration will result. The corresponding figure for Surveyor I is 9.83 psi.

2.4 <u>Comparison with Surveyor I Data</u>

In the previous report several sets of soil parameters were obtained which, in the simulation, produced footpad penetrations of 0.25 feet, in agreement with data obtained from Surveyor I. The same sets of soil parameters have been re-run with the new Surveyor shock absorber. The results are listed in Table III.

The penetration results using the new Surveyor shock absorber indicate that with the same landing conditions, one would expect Surveyor to penetrate the lunar surface approximately 0.5 feet. The crush block penetrates the surface about 0.3 feet, a figure similar to that obtained with the Surveyor I shock absorber.

It may be concluded that if the soil model used in this simulation is adequate to describe the lunar surface, if the soil at the landing site of future Surveyors is the same as at the site of Surveyor I, and if the same spacecraft landing conditions exist, the change in the shock absorber will cause the future Surveyors to penetrate about twice as far.

It is not intended to suggest that each of the sets of soil parameters in Table III is an equally likely candidate for a description of the lunar surface. Visual observations at both the Surveyor I and the Surveyor III sites suggest that a density of 3 slugs per cubic foot and an internal friction angle between 30° and 40° represent the most likely soil parameters.[4]

ACKNOWLEDGEMENT

It is a pleasure to acknowledge the assistance of Mrs. C. A. Friend in revising the computer program.

E. N. Shipley

E. N. Shipley

1014-ENS-jan

Attachments
  Tables I - III
  Figures 1 - 8

REFERENCES

1. E. N. Shipley, "Surveyor and LM Penetration into a Model Lunar Soil", Bellcomm Technical Memorandum 67-1014-1, February 23, 1967.

2. P. L. Chandeysson, "Calculating Dynamic Soil Bearing Strength for Vertical Landing Spacecraft", Bellcomm Memorandum for File, December 7, 1966.

3. The new shock absorber is formally called the "Surveyor Spacecraft Landing Gear Shock Absorber Column", and is Part No. 238945, Revision B. The characteristics of the new shock absorber were obtained from R. H. Jones, Hughes Aircraft Company, private communication.

4. R. F. Scott, F. I. Roberson and M. C. Clary, Section V, "Surveyor III - Preliminary Science Results", Jet Propulsion Laboratory PD-125, May 15, 1967.

Spacecraft	
Surveyor Mass (at touchdown)	20.0 slugs
Touchdown velocity	11.7 ft/sec
Shock Absorber	
Preload force	300 pounds
Spring force	See Figure 1
Damping function	See Figure 2
Friction force	40 pounds + .03 x (spring force)
Crush Block	
Crushing pressure	40 psi
Radius	.34 feet
Footpad	
Radius	.33 feet

TABLE I

Surveyor Parameters Used in the Present Simulation

Φ	ρ = 1 slug/ft^3	ρ = 3 slugs/ft^3
0°	.04 psi/foot	.11 psi/foot
10°	.10 "	.31 "
20°	.30 "	.89 "
30°	.92 "	2.8 "
40°	3.1 "	9.4 "

TABLE II

RATE OF INCREASE OF THE STATIC BEARING CAPACITY WITH PENETRATION INTO THE LUNAR SURFACE. THE UNITS ARE PSI PER FOOT OF PENETRATION. Φ IS THE INTERNAL FRICTION ANGLE OF THE SOIL.

SOIL PARAMETERS				PENETRATION, NEW SHOCK ABSORBER	
Internal Friction Angle	Density (slugs/ft^3)	Cohesion (psi)	Static Bearing Capacity, Surveyor Footpad (psi)	Footpad (feet)	Crush Block (feet)
0	1	.95	6.35	.69	.37
0	3	.95	6.35	.65	.34
10	1	.55	6.44	.66	.36
10	3	.54	6.34	.64	.34
20	1	.30	6.28	.69	.37
20	3	.30	6.36	.60	.32
30	1	.116	6.22	.64	.36
30	3	.104	5.98	.55	.32
40	1	.038	5.98	.51	.34
40	3	.015	5.06	.37	.30

TABLE III

Penetration of a Surveyor Footpad In Soils Whose Parameters Have Been Chosen To Agree With Surveyor I Data

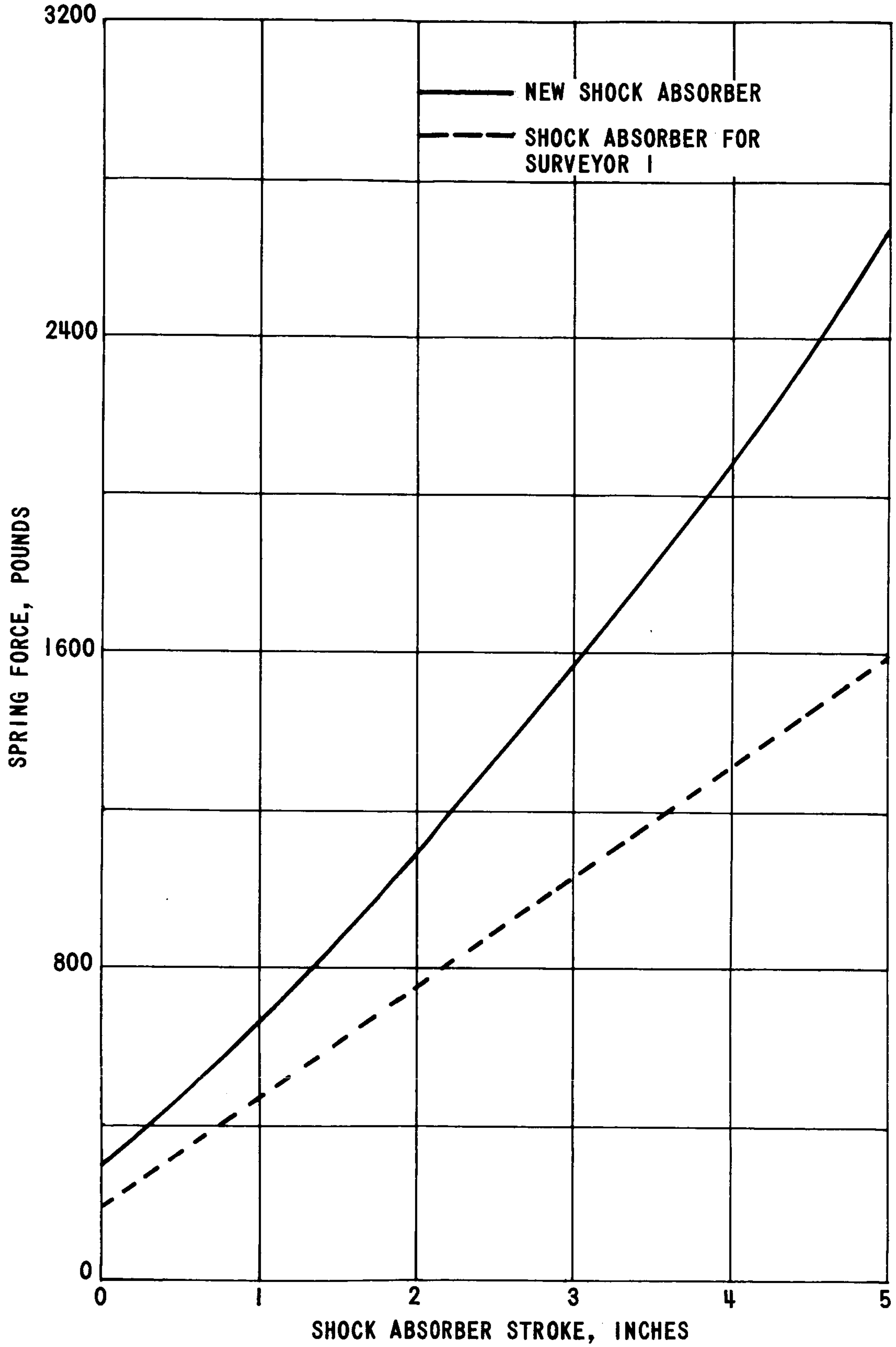

FIGURE I - SPRING FORCE FOR THE SURVEYOR SHOCK ABSORBER. THE GRAPHS INCLUDE THE PRELOAD FORCE

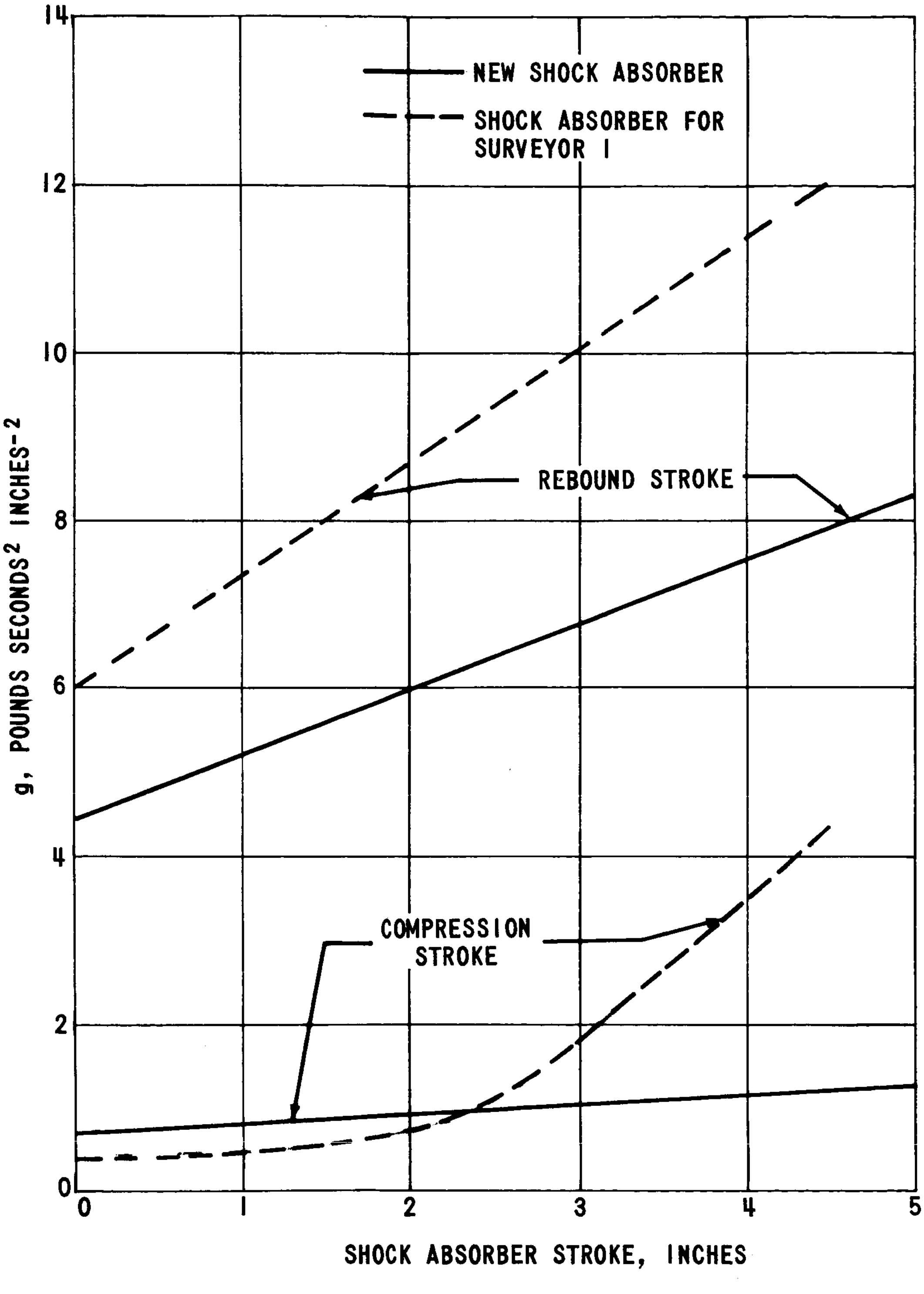

FIGURE 2 - COMPARISON OF THE DAMPING CONSTANT FOR THE SURVEYOR SHOCK ABSORBER

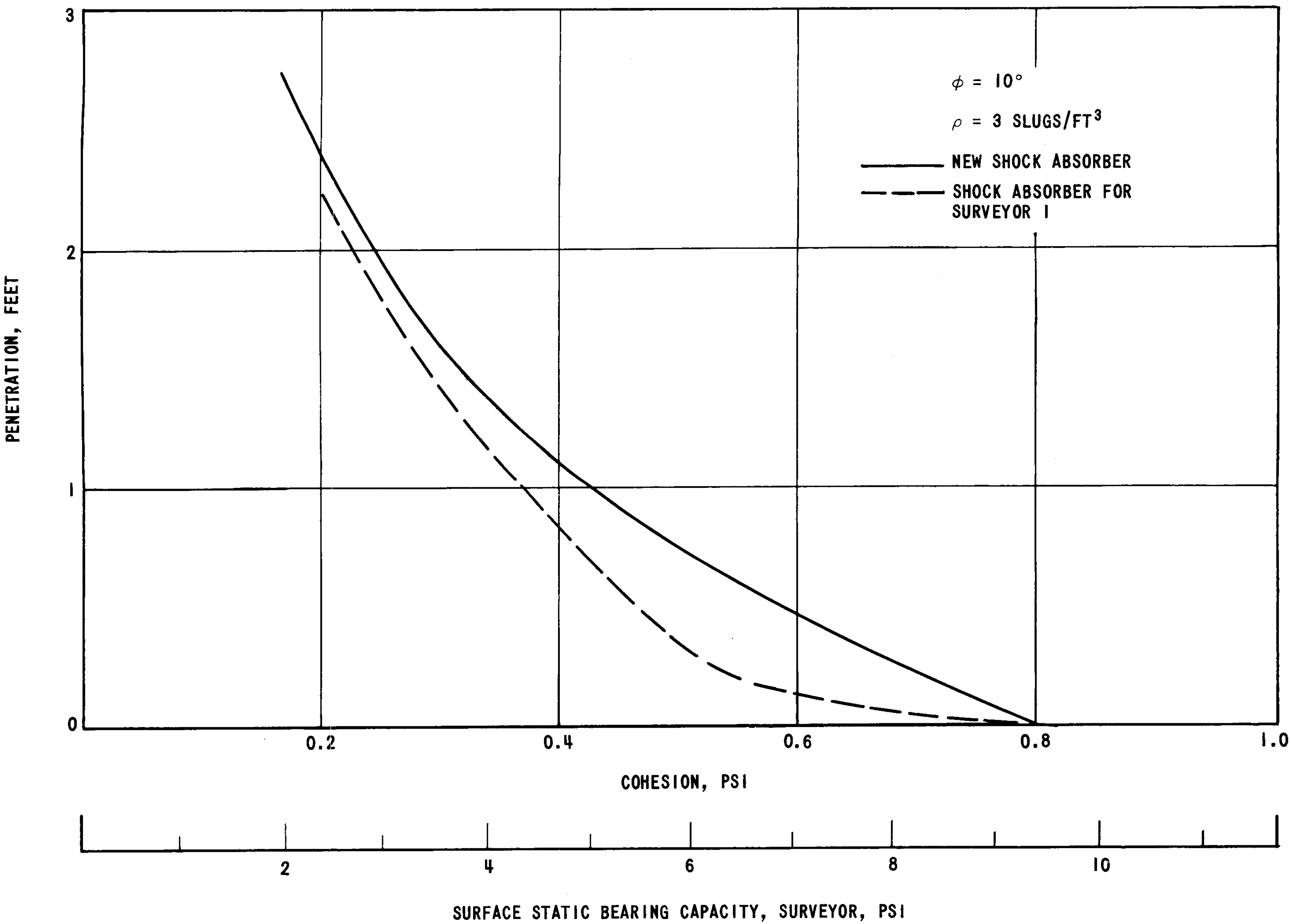

FIGURE 3 - SURVEYOR FOOTPAD PENETRATION AS A FUNCTION OF COHESION. THE CONDITIONS UNDER WHICH THE SIMULATION WERE CONDUCTED ARE GIVEN IN TABLE I

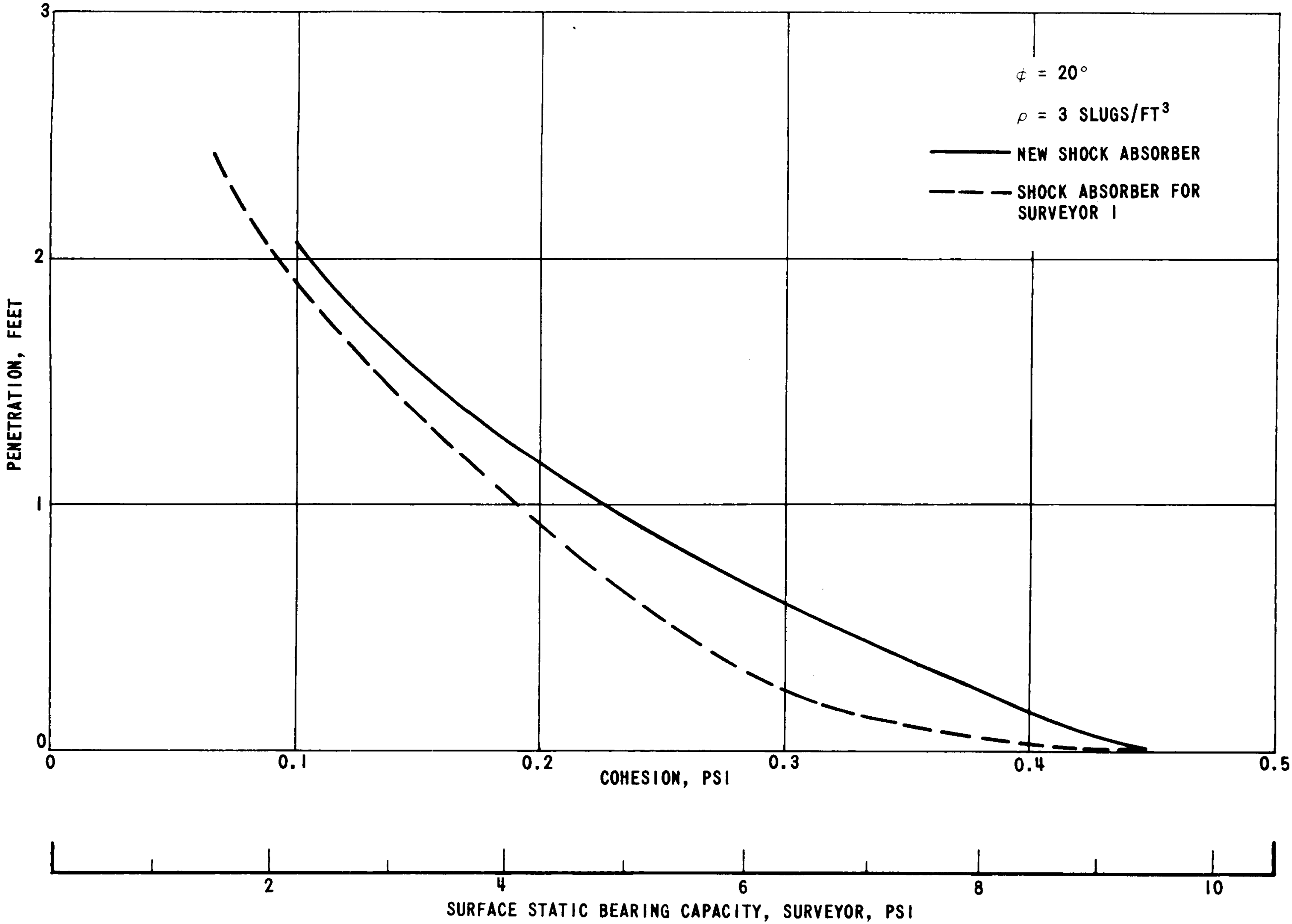

FIGURE 4 - SURVEYOR FOOTPAD PENETRATION AS A FUNCTION OF COHESION. THE CONDITIONS UNDER WHICH THE SIMULATION WERE CONDUCTED ARE GIVEN IN TABLE I

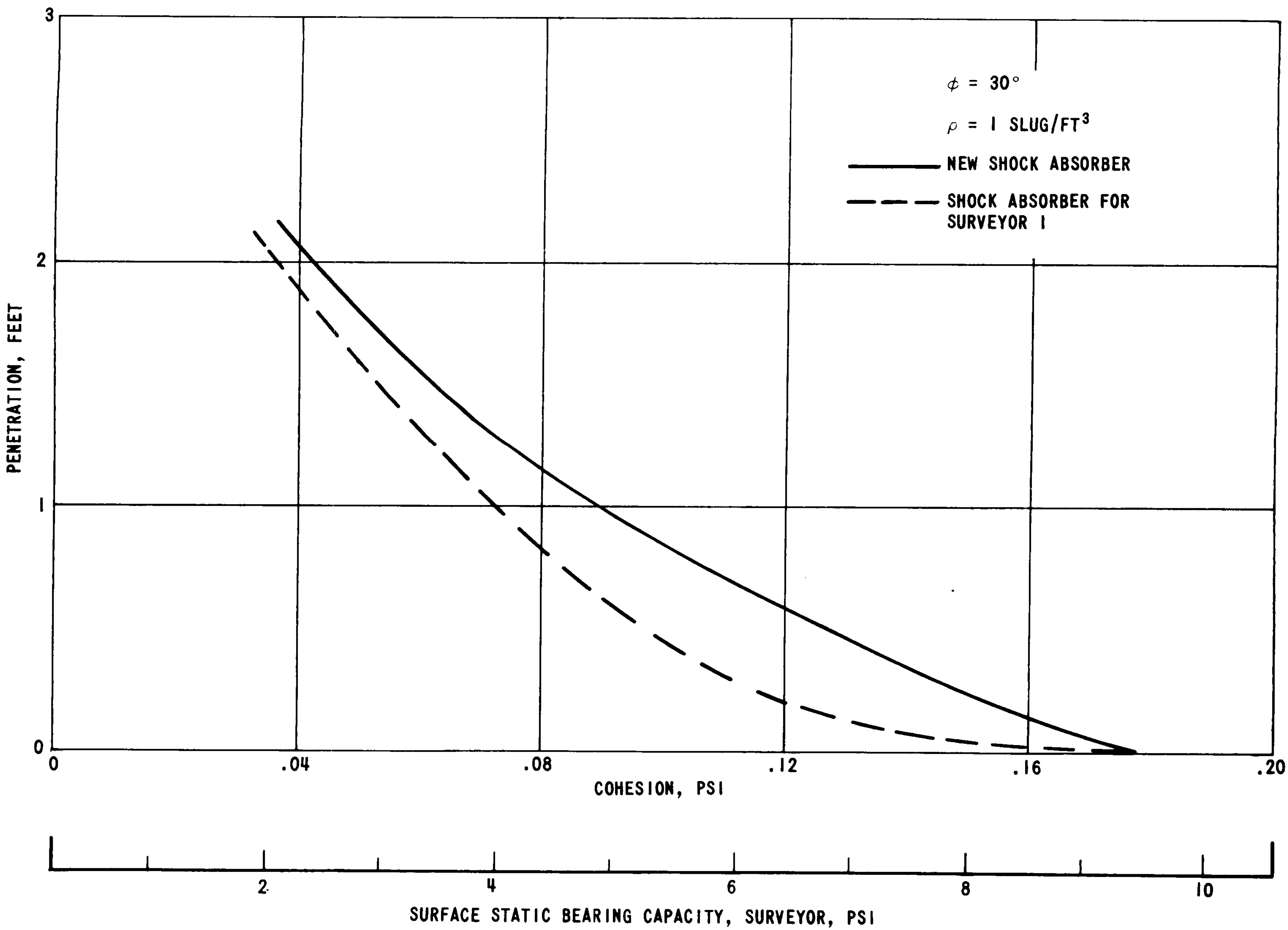

FIGURE 5 - SURVEYOR FOOTPAD PENETRATION AS A FUNCTION OF COHESION. THE CONDITIONS UNDER WHICH THE SIMULATION WERE CONDUCTED ARE GIVEN IN TABLE I

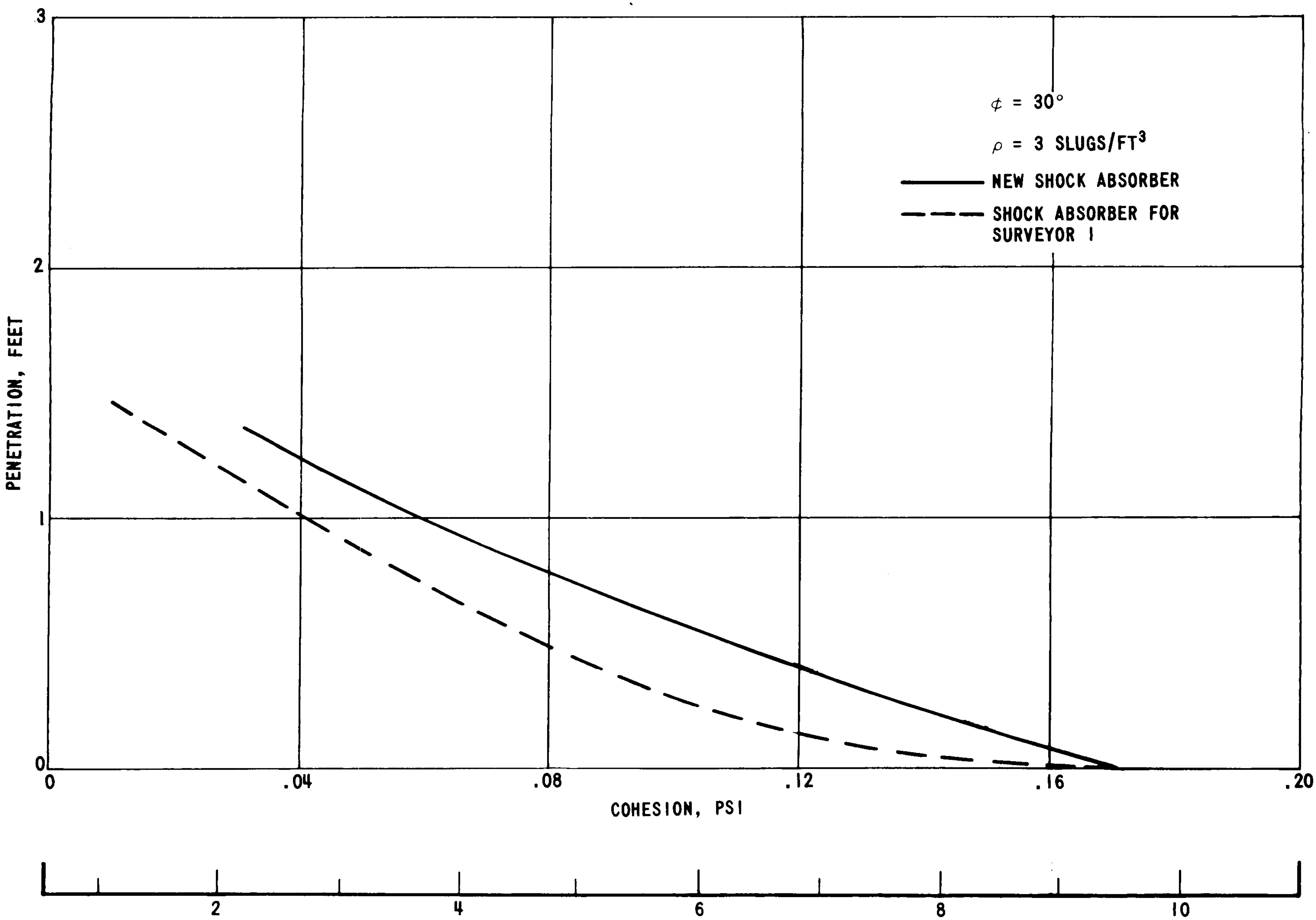

FIGURE 6 - SURVEYOR FOOTPAD PENETRATION AS A FUNCTION OF COHESION. THE CONDITIONS UNDER WHICH THE SIMULATION WERE CONDUCTED ARE GIVEN IN TABLE I

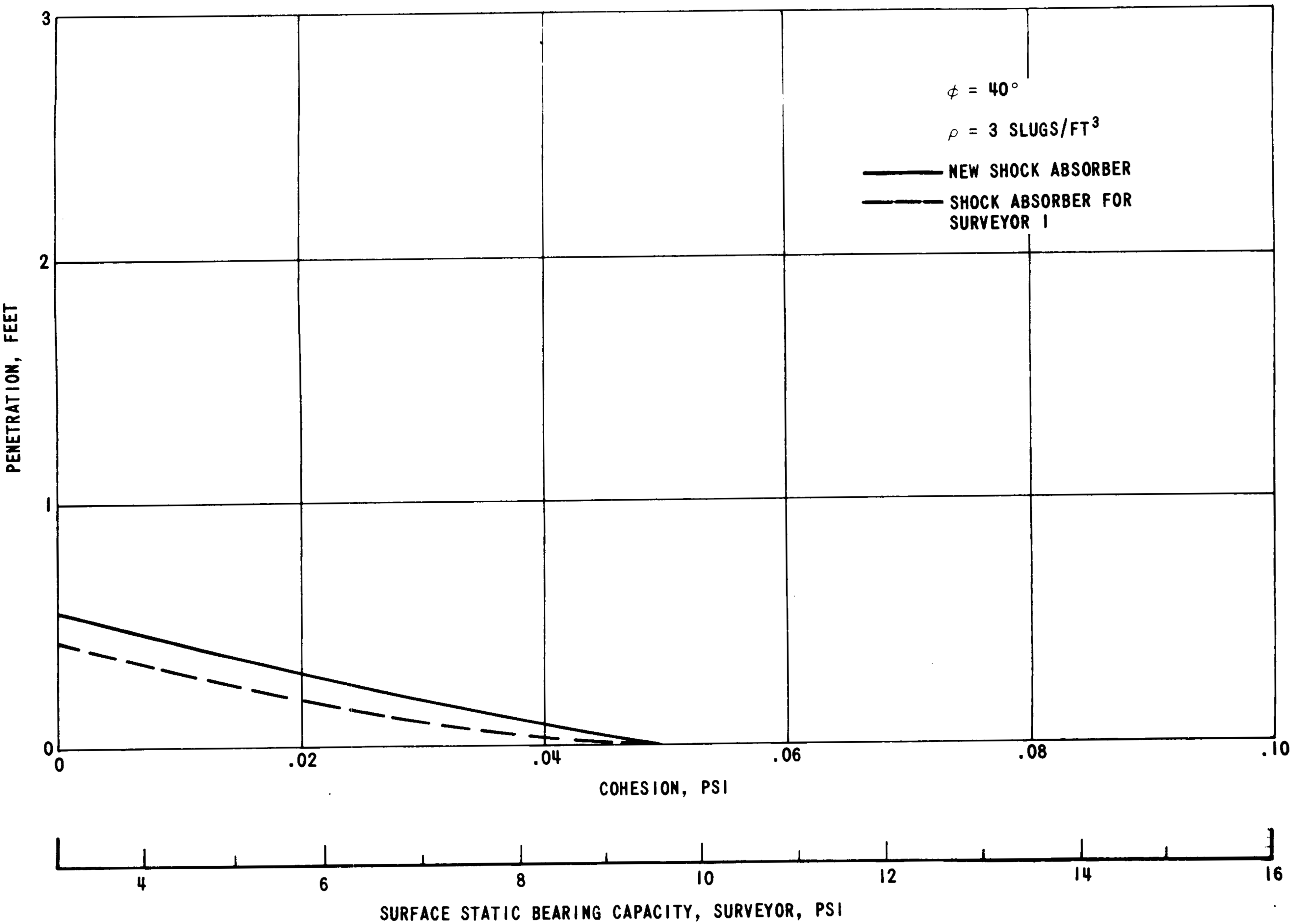

FIGURE 7 - SURVEYOR FOOTPAD PENETRATION AS A FUNCTION OF COHESION. THE CONDITIONS UNDER WHICH THE SIMULATION WERE CONDUCTED ARE GIVEN IN TABLE !

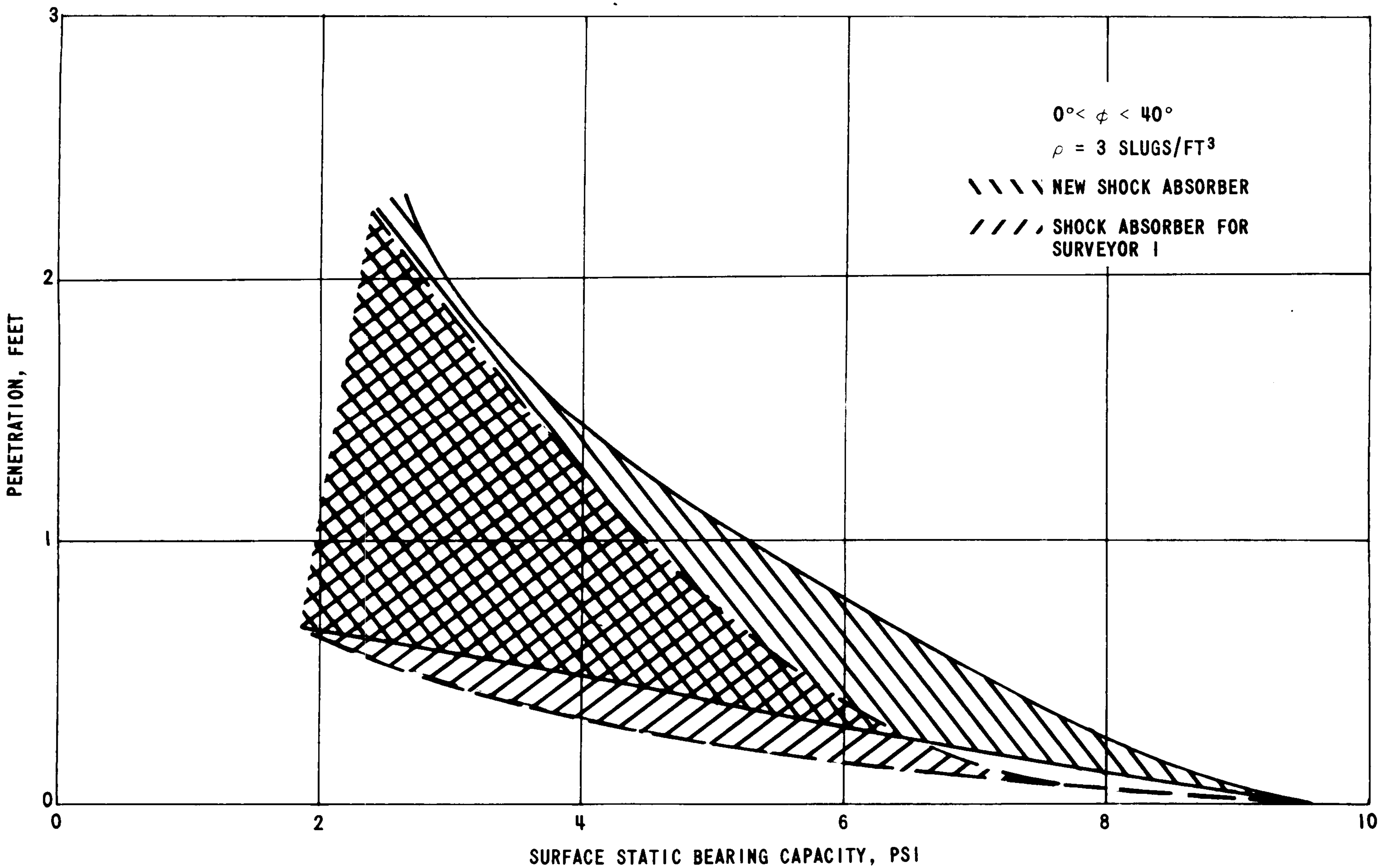

FIGURE 8 - RANGE OF SURVEYOR FOOTPAD PENETRATIONS AS A FUNCTION OF THE SURFACE BEARING CAPACITY OF THE SOIL